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AV Trajectories: Newtonian Mechanics vs. The Real World

The Autonomous / Chapter Event
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EDGE CASE RESEARCH

Overview

- **Limits on trajectory control**
  - Vehicle capability
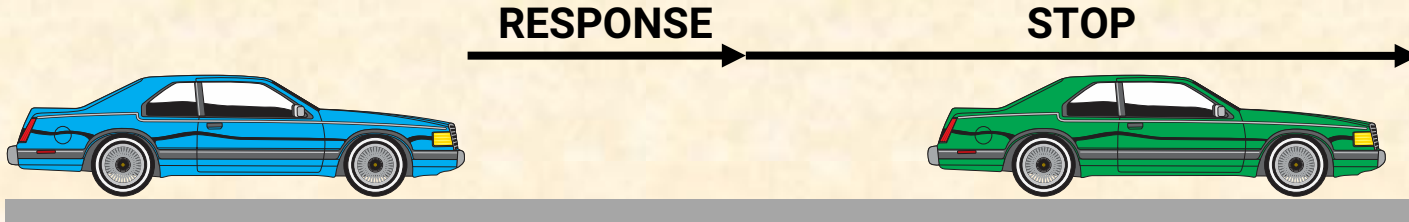 - Environmental conditions

- **Uncertainty**
  - About vehicle conditions
  - About environment

- **Managing ODD variations**
  - Micro-ODDs as an approach

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EDGE CASE RESEARCH

Example: Safe Following Distance

RESPONSE   STOP

■ **Follower stops with space left behind leader (RSS example)**
- Different initial speeds
- Follower initially accelerating during response time
- Different braking capabilities
- Considered safe if any gap between vehicles at rest

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F=MA

Not Just
A Good Idea
…

It's the Law!

Sir Isaac Newton

But, Where Does the "A" Come From?

- **F = MA ➜ A = M / F**
  - BUT … F is limited by tire friction force

$$F_{friction} = \mu * F_{normal} \tag{6}$$

where:
- $F_{friction}$ is the force of friction exerted by the tires against the roadway
- μ is the coefficient of friction, which can vary for each tire
- F_{normal} is the force with which the vehicle presses itself onto the road surface

- **Example: braking depends upon:**
  - Ability of vehicle to exert force on roadway ($F_{friction}$)
  - Driver applying full $F_{friction}$ via brakes (braking capacity)

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Road Conditions Affecting Braking

- ■ **Slopes**
  - ● **Decreases friction AND pulls car**

- ■ **Curves:**
  - ● **Friction maintains centripetal force**
  - ● **Banking (superelevation)**
    - – **Reverse bank reduces normal force**

- ■ **Road surface condition**
  - ● **Dry concrete**   **μ = 0.75**
  - ● **Snow**   **μ = 0.2 – 0.25**
  - ● **Ice**   **μ = 0.1 – 0.15**

A_{brake}

μ

μ

$F_{normal} = mg\,cos\theta$

$A_{hill} = g\,sin\theta$

Slope θ

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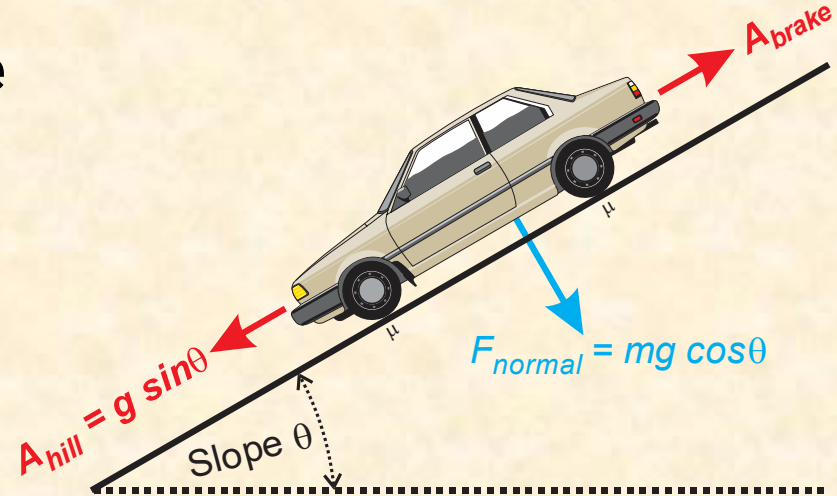
Other Factors Affecting Brake Force

- **Braking capability:**
  - Tire capability ("sticky" tires might have μ > 1)
  - Brake maximum friction (pad wear)
- **Equipment condition**
  - Tire condition: temperature, pressure, tread
  - Brake condition: hot, wet, damaged, …
  - Vehicle suspension, weight distribution, …
- **Braking controls**
  - Driver leg strength and willingness to brake hard
  - Braking assist force (multiplies driver leg strength)
- **Aerodynamics, suspension, debris, …**

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Epistemic Uncertainty – Vehicles

- **Own vehicle weak braking (less than expected)**
  - Brake wear & failures
  - Loss of brake assist
  - High tire pressure / bald tires
  - Brakes hot from recent use
  - Brakes wet from recent puddle
- **Other vehicle strong braking**
  - Braking capability for vehicle type
  - Aftermarket brake upgrade?
  - Aftermarket tire upgrade? Low tire pressure?
 - Leg strength of lead driver to press brakes?

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Epistemic Uncertainty – Environment

- **Road surface of own vehicle**
  - Might not be same as lead vehicle surface
- **Road surface of lead vehicle**
  - Might have dramatically different friction properties

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BRIDGE MAY ICE BEFORE ROADWAY

EDGE CASE RESEARCH

Segmenting Into Micro-ODDs

- **A single huge ODD leads to poor permissiveness**
  - Want better performance on a warm dry day
- **Approach: break up ODDs into pieces**
  - Default cautious behavior
  - Prove safe trajectory for an ODD segment
  - Optimize segments based on customer value

ENTIRE ODD

HOT

WARM+ DRY+ FLAT+ HIGHWAY

COLD

WET ⟷ DRY

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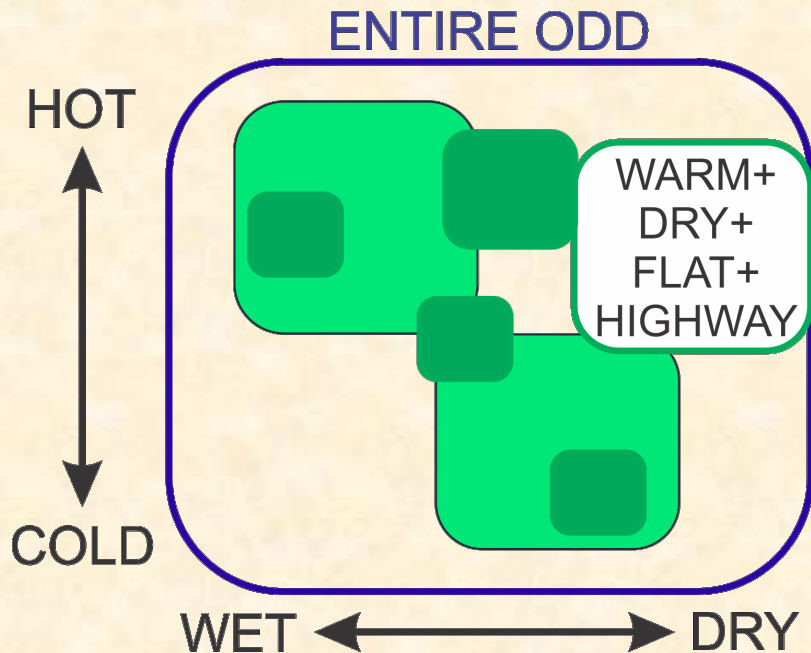
Micro-ODD Benefits

- **Turns ODD growth on its head:**
  - Over time: Improve permissiveness for fixed ODD size
  - Operate across a diverse ODD safely (and cautiously!)
  - Incrementally improve performance in high value ODD segments
  - Use finer grain ODD segments for high value operational situations
   - Note: important to address transition between segments
- **References:**
  - Micro-ODD paper: https://arxiv.org/abs/1911.01207
  - ODD parameter paper: https://bit.ly/33K26uA
  - UL 4600
    - Sections 8.2 (ODD) & 8.8 (Trajectory & Control)

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Conclusions

- **Proofs are great, but rely upon assumptions**
  - In particular, about environment & behaviors
  - Permissiveness vs. safety tradeoffs

- **Proofs push uncertainty into the assumptions**
  - Uncertainty about own system
  - Uncertainty about other actor behaviors
  - Uncertainty about the environment

- **You might forget the edge cases…**

  … but they won't forget you!
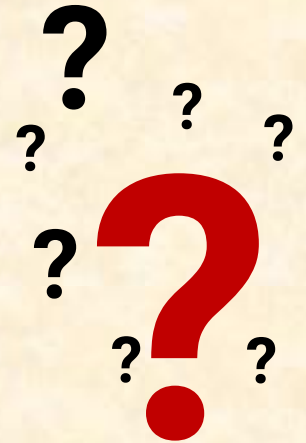
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WE DELIVER THE PROMISE OF AUTONOMY